

ISO 9001:2015 Certified



Technical Guidelines for the Operation and Management of Biogas Facilities

1. Introduction

Anaerobic digestion (AD) facilities comprise several key processes, including feedstock reception and pretreatment, AD itself, biogas utilization, sludge and wastewater treatment, and odor control. Among these, the AD process is central, as it generates methane-rich biogas. Its advantages include methane recovery, reduced sludge generation, and lower maintenance costs. However, drawbacks such as high temperature requirements, slow microbial response, and odor issues remain. Key operational parameters include hydraulic retention time (HRT) and temperature. Higher temperatures accelerate digestion rates but also increase energy consumption and may reduce microbial stability. Mesophilic conditions (35–42 °C) are generally considered the most stable for operation. pH plays a critical role in microbial activity: acidogenic bacteria are most active between pH 5.0–6.2, while methanogens prefer pH 6.5–8.0. Alkalinity acts as a buffer and, together with volatile fatty acids (VFAs), serves as an indicator of pH stability. Sudden pH changes signal process imbalance and require proactive management. Nutrient balance is essential, particularly the appropriate ratio of carbon, nitrogen, phosphorus, and sulfur (C/N/P/S), as well as trace elements such as Co, Ni, Mo, and Se. A deficiency or excess of these can inhibit methanogenesis or lead to the accumulation of toxic metals. In food waste digestion, trace element supplementation may be necessary due to inherent nutrient deficiencies.

Common inhibitors during digester operation include high concentrations of VFAs, ammonia, heavy metals, and sulfur compounds all of which can suppress microbial activity.

Additionally, oxygen intrusion is harmful to anaerobic microbes, making strict sealing critical. Mixing is vital to ensure contact between microbes and substrates and to prevent sedimentation and scum formation. Both over- and under-mixing can reduce efficiency; therefore, mixing effectiveness should be monitored using parameters such as temperature uniformity, solids concentration, and dead zone formation. Digestibility varies depending on the substrate's organic content and loading rate. For food waste, organic removal efficiency can exceed 80% under a loading rate of 3 kg VS/m³·d. In contrast, livestock manure, which has lower organic content, is typically operated at lower loadings. Biogas primarily consists of methane (CH₄), carbon dioxide (CO₂), hydrogen (H₂), and hydrogen sulfide (H₂S). Methane is the main energy component, typically accounting for 55–70% of the biogas. CO₂ and H₂ are intermediate byproducts of decomposition, while H₂S is corrosive and must be removed through separate treatment.

Scum and foam can reduce digestion efficiency and are often caused by overloading or improper feedstock management. These are typically controlled using mechanical methods such as rotating rakes, mixing, or spraying. Process disturbances commonly manifest as VFA accumulation, pH drops, and reduced methane content. Early detection and timely response are crucial. Causes may include nutrient imbalance, temperature fluctuations, toxic compound introduction, or organic overload. In such cases, adjusting feed rates and stabilizing environmental conditions can help recover process stability. The following section summarizes tables outlining the key parameters and operational guidelines required for effective digester operation.

2. Current working condition for anaerobic digesters in Arusha, Tanzania

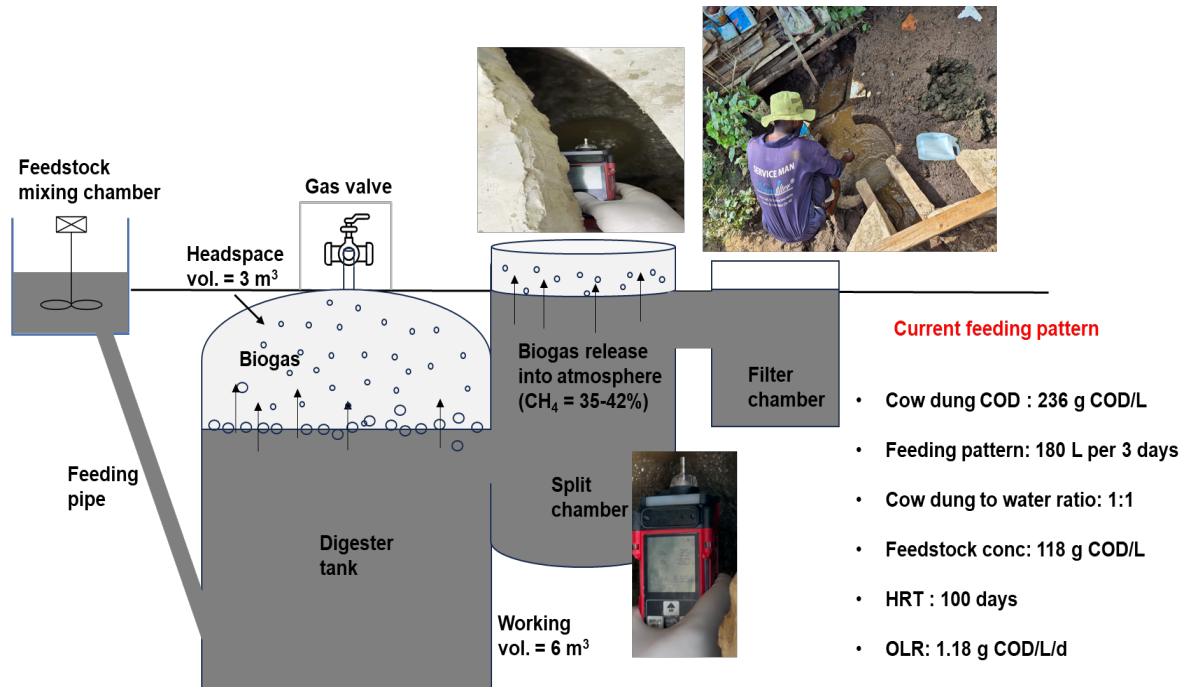


Fig. 1. Current operating condition of biogas plant in Arusha Tanzania.

The retrofitted biogas digester covered under this project had a working volume of 6 m³ and headspace of 3 m³. After retrofitting the operating condition such as organic loading rate (OLR) and HRT were quite low as mentioned in Fig. 1. In the next section we have mentioned the ideal operating parameters, and steps to be taken to characterize the feedstock and increase the understanding of effective operations and maintenance for the performance of the quite complex systems. This document has been prepared while keeping in mind the current scenario of the biogas digester in Arusha, Tanzania and shall be refer to the biogas operators and stakeholders. The stakeholders can use the below information and standard to maximize the biogas productivity, while minimizing the failure risks of the digester and any hazardous risk such as odor problem, sludge toxicity.

This report has been prepared based on information taken from the “**Technical Guidelines for the Operation and Management of Co-Digestion Biogas Facilities**” (2nd Revised Edition) Ministry of Environment, South Korea, published in 2017. Hence the parameters and standards below are provided to support long term operation of biogas digester. This report

has been divided into two parts Part I: General aspects of a biogas plants and standard protocol for operating biogas plants and methodologies to evaluate its performance based on different results obtained through different parameters. It has been summarized from Table 1 to 6. While Part II: Measures taken to minimize the failure of biogas plants and improve efficiency by observing the checklist mentioned as the deciding factor for unhindered operation of biogas plants. It has been summarized from Table 7 to 13.

Part I: General aspects of biogas plants and standard protocol for operating biogas plants and methodologies

Table 1 summarizes the essential operational parameters to consider when designing anaerobic digesters. Particularly, OLR, HRT, temperature, and pH greatly influence digestion efficiency and gas production and are the basis of process stability.

Table 1. Key Operating Factors for Anaerobic Digesters

Parameter	Condition and Range
Reactor Type	Wet / Dry
Temperature	Mesophilic (35–38°C), Thermophilic (50–55°C)
pH	6.5–8.0 (single-stage), 4.5–6.5 (acidogenesis), 7.0–8.0 (methanogenesis)
Organic Loading Rate (OLR)	Wet: 1.5–4.0 kg-VS/m ³ ·d, Dry: 2.5–5.0 kg-VS/m ³ ·d
HRT	Mesophilic: at least 20 days, Thermophilic: at least 15 days

Table 2 presents the optimal concentration ranges of trace elements essential for methanogenic microbial activity. A lack of these elements can reduce microbial activity and biogas production, making regular monitoring and supplementation necessary.

Table 2. Trace Element Standards and Functions

Element	Standard (mg/kg TS)	Standard (mg/L)

Cobalt (Co)	0.4–10 (opt. 1.8)	0.06
Molybdenum (Mo)	0.05–16 (opt. 4)	0.05
Nickel (Ni)	4–30 (opt. 16)	0.006
Selenium (Se)	0.05–4 (opt. 0.5)	0.008
Iron (Fe)	750–5,000 (opt. 2,400)	1–10
Tungsten (W)	0.1–10 (opt. 1.0)	0.005
Zinc (Zn)	10–300 (opt. 100)	0.05
Manganese (Mn)	10–200 (opt. 50)	0.02
Copper (Cu)	2–100 (opt. 20)	0.01

Table 3 summarizes the operating temperature ranges and typical management characteristics for anaerobic digestion systems. It compares low-temperature, mesophilic, and thermophilic digestion processes to help determine the optimal operational conditions based on energy use, management complexity, and temperature requirements.

Table 3. Operating Conditions by Digestion Temperature

Category	Low-Temperature Anaerobic Digestion	Mesophilic Anaerobic Digestion	Thermophilic Anaerobic Digestion
Temperature range (°C)	20 ~ 25	35 ~ 42	50 ~ 60
Operating conditions	- Easy to manage - No heating required	- Easy to manage - Requires heating in summer - Can utilize self-generated energy for heating	- Difficult to manage - Heating required - High operating cost

Table 4 outlines the concentration thresholds of substances that may inhibit microbial activity

within anaerobic digesters. High concentrations of VFA, ammonia, sulfides, salts, and heavy metals can hinder digestion or shut down biological activity, necessitating regular monitoring.

Table 4. Inhibitory Substance Thresholds in Digesters

Substance	Inhibitory Concentration (mg/L)
VFA	>3,000 (acetic acid base)>4,000 (for food waste)
Ammonia	>3,000 (at pH > 7.6)
Soluble Sulfides	>3,000
Calcium	2,500–4,500
Magnesium	1,000–1,500
Potassium	2,500–4,500
Sodium	3,500–4,500
Copper	>0.5
Cadmium	>150
Iron	>1,700

Table 5 provides criteria and methods to evaluate the internal mixing conditions of anaerobic digesters. Proper mixing ensures uniform distribution of solids and temperature and prevents sludge sedimentation or dead zones.

Table 5. Mixing Efficiency Evaluation Criteria

Item	Evaluation Criteria	Measurement Method
Internal temperature	±1 °C	Measure by reactor level
Solids concentration	±10%	Measure by reactor level
FS (Fixed Solids) discharge	±2%	Compare influent vs. effluent FS

Dead zone range	<10%	Pre-evaluation via computational fluids dynamics (CFD) modeling
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Table 6 compares the physical and chemical properties of incoming food waste, mixed sludge fed into the digester, and digested sludge after the process. Each item includes both a range and representative value to assist with design and operational decisions.

Table 6. Sludge Characteristics Comparison

Characteristic	Food Waste	Digester Feed Sludge	Digested Sludge
	Range / Mean	Range / Mean	Range / Mean
TS (%)	15.9–26.0 / 20.0	6.0–14.0 / 10.0	2.5–5.1 / 3.8
VS (%)	14.3–20.0 / 16.3	3.6–11.5 / 8.5	0.9–2.5 / 1.9
FS (%)	1.6–6.0 / 3.7	0.9–2.5 / 1.5	0.9–2.6 / 1.9
VS/TS ratio	0.7–0.9 / 0.8	0.6–0.9 / 0.85	0.3–0.7 / 0.5
Moisture content (%)	74.0–84.1 / 80.0	85.0–95.0 / 90.0	95.0–98.0 / 96.2

Table 7 summarizes common operational issues in anaerobic digesters, their causes, and corresponding countermeasures. Typical problems include reduced biogas production, poor effluent quality, pH drop, and abnormal foaming. Each issue is linked to factors such as organic overloading, temperature fluctuations, and insufficient mixing. Proper diagnosis and timely corrective actions—like adjusting loading rates or improving mixing are essential for Table operation.

Part II: Operational checklist and suggested solutions based for specific problems arises during the operation of biogas plant.

Table 7. How to develop solutions based on specific causes during anaerobic digester operation

Condition	Cause	Countermeasure
1. Reduced biogas production	<ul style="list-style-type: none"> - Inflow of low-concentration sludge -Over-discharge -Temperature drop -Reduced digester volume -Biogas leakage -Excessive acid formation 	<ul style="list-style-type: none"> - Increase sludge concentration -Adjust discharge rate -Raise temperature and check boiler system -Dredge sediment if volume reduced -Repair leakage -Monitor for acid overproduction
2. Deteriorated supernatant quality	<ul style="list-style-type: none"> - Same as above -Overmixing -Inflow of digested sludge 	<ul style="list-style-type: none"> - Apply same solutions as item 1 -Adjust mixing intensity/pattern -Optimize discharge timing
3. pH drop / Weak gas / Excess scum	<ul style="list-style-type: none"> - Organic overloading -Temperature drop -Insufficient mixing -Methanogen inhibition -Toxic or heavy metal substances 	<ul style="list-style-type: none"> - Reduce loading or partially dewater -Maintain temperature -Adjust mixing -Identify/remove toxic input, consider sludge replacement
4. Beer foam-type abnormal foaming	<ul style="list-style-type: none"> - Excess sludge discharge -Organic overload -Temperature drop -Scum build up -Sediment accumulation 	<ul style="list-style-type: none"> - Pause discharge and add sludge -Mix thoroughly -Raise temperature -Remove scum -Dredge if needed

Table 8 outlines the key operational parameters of anaerobic digestion facilities, including units and recommended measurement frequency. Consistent monitoring of these parameters is essential for maintaining process stability, optimizing biogas production, and detecting potential issues early.

Table 8. Operational Parameters and Measurement/Recording Frequency

Operational Parameter	Unit	Frequency
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Inflow volume	ton	Daily
Temperature	°C	Daily
pH	-	Daily
Biogas production	m ³	Daily
Biogas composition	Methane vol %, CO ₂ , H ₂ S, optionally O ₂	Daily
Biogas yield	m ³ /kg VS	Daily
OLR	kg VS/(m ³ ·d)	Daily
Retention time	days	Daily
VFA	mg/L	Daily
Methane content	%	Daily
Digestate (sludge) generation	kg TS/m ³ , kg VS/m ³	Weekly
Total nitrogen (TN)	mg/L	Weekly
TS, VS of influent	%	Weekly
TS, VS of effluent	%	Weekly
Alkalinity	mg/L	Weekly
COD	mg/L	Weekly
Ammoniacal nitrogen (NH ₄ ⁺ -N)	mg/L	Weekly
Heavy metals	mg/L	As needed
Trace elements	mg/L	As needed

Tables 9 and 10 present example checklists for ensuring stable operation of biogas facilities. Table 9 focuses on key operational parameters such as digester temperature, pH, retention time, and loading rate, comparing performance standards with actual operating data. Table 10 includes items related to sludge and biogas treatment, odor control, and monitoring equipment management. Together, these tables help operators maintain system efficiency and prevent potential issues through routine inspections.

Table 9. Example Operation Checklist for Biogas Plant (1)

Item		Std.	Operation status	Notes
Operating Conditions	treatment amount	Food waste		
		Leachate from food waste		
	Digester operation	Temperature (°C)		
		pH		
		HRT (day)		
		Volumetric loading rate (kg VS/m ³ ·day)		
		Volumetric loading rate (kg COD/m ³ ·day)		
	Digester Influent	TS		
		VS		
		COD(mg/L)		
Operational Efficiency	Removal efficiency	TS		
		VS		
		COD (mg/L)		
	biogas	Production (Nm ³ /d)		
		Methane (%)		
	Biogas yield (Nm ³ /kg)	Per unit VS input		
		Per unit VS removed		
		Per unit COD input		
		Per unit COD removed		
		Per ton of influent		
	methane yield (Nm ³ /kg)	Per unit VS input		
		Per unit VS removed		
		Per unit COD input		
		Per unit COD removed		
		Per ton of influent		

Table 10. Example Operation Checklist for Biogas Plant (2)

Item	Performance Standard	Operating Status	Remarks
Digester temperature (°C)	(±)	(±)	±2 for mesophilic, ±1 for thermophilic
Digester pH	(±)	(±)	Appropriate range: 7.0–8.0
Volumetric loading (kg VS/m ³ ·day)	(±)	(±)	Within ±15%, recommended with damping
Volumetric loading (kg COD/m ³ ·day)	(±)	(±)	Within ±15%, it may vary depending on process
Methane content (%)	(±)	(±)	Typically, 55–70%
VFA (mg/L)	(±)	(±)	Below 4,000 mg/L preferred
Alkalinity (mg/L)	(±)	(±)	
VA / Alkalinity ratio	(±)	(±)	≤ 0.3 is considered stable
VFA (mg/L)	(±)	(±)	
NH ₄ ⁺ (mg/L)	(±)	(±)	Below 3,000 mg/L
NH ₃ (mg/L)	(±)	(±)	
C/N ratio	(±)	(±)	Optimal range: 10–30
Oil & grease (n-Hexanol extraction, mg/L)	(±)	(±)	

Table 11 outlines the commissioning and operation procedures for a biogas facility after construction. It includes timelines for trial operation, reliability testing, and performance verification, as well as requirements for planning, staffing, and documentation. Key tasks such as checklist preparation, technical support, and operator training are also specified. The process ensures systematic evaluation and reporting to relevant authorities for successful facility operation.

Table 11. Commissioning and Reliability Test Procedure

Category	Task Description	
Construction Conditions	<ul style="list-style-type: none"> - From the date of facility completion: () days - Operation period requirement: at least 10 months after completion and final inspection (includes 2 months after performance test) - Performance test obligation: at least 2 years after commissioning 	
Integrated Facility Operation Plan Preparation	<ul style="list-style-type: none"> - Establish operation schedule and staffing plan - Prepare comprehensive plan for execution 	<ul style="list-style-type: none"> ※ Submit planned schedule and responsible personnel ※ Submit integrated operation plan
Pre-inspection and Checklist Preparation	<ul style="list-style-type: none"> - Prepare checklists - Create detailed commissioning procedures 	<ul style="list-style-type: none"> ※ Check equipment and facility installation before commissioning ※ Compare with design documents and drawings
Trial Operation	<ul style="list-style-type: none"> - Operate all units (e.g., waste reception, water supply, mixing, and anaerobic digestion) 	<ul style="list-style-type: none"> ※ Record input amounts and biogas generation ※ Collect and analyze treatment performance data ※ Report results
Reliability Test Operation	<ul style="list-style-type: none"> - Evaluate operation stability and facility performance - Perform continuous operation for at least 30 days 	<ul style="list-style-type: none"> ※ Conduct reliability test operation at least 2 months after commissioning and 10 months after completion
Technical Support and Operation Management	<ul style="list-style-type: none"> - Perform technical tasks and coordination - Analyze air quality and operational efficiency 	<ul style="list-style-type: none"> ※ Provide operator education ※ Conduct domestic and overseas training (if

		necessary)
Facility Evaluation and Reporting	<ul style="list-style-type: none"> - Prepare evaluation reports based on test results - Submit reports and documentation authorities 	<ul style="list-style-type: none"> ※ Submit operational performance reports and evaluation forms to relevant

Table 12 outlines the step-by-step operational tasks required for the commissioning and testing of a biogas facility. Table 12 summarizes the commissioning process of biogas facilities in 3 stages, clearly describing the scope and inspection content at each stage.

Table 12. Commissioning Items and Details for Biogas Facilities

Category	Scope	Details
Pre-commissioning	Unit equipment installation inspection	<ul style="list-style-type: none"> - Check electrical/instrument control equipment - Conduct facility protection inspection
	Unit operation (temporary operation)	<ul style="list-style-type: none"> - Temporarily operate individual units and conduct subsystem testing
Commissioning	Installation inspection	<ul style="list-style-type: none"> - Confirm installation and function of each unit - Record commissioning status
	Operational inspection	<ul style="list-style-type: none"> - Conduct integrated operation and function check of each unit - Record operational status
Performance test	Performance test &	<ul style="list-style-type: none"> - Verify performance of

	inspection	installed equipment against design specifications - Confirm stable and continuous operation during reliability test
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Table 13 outlines the key inspection items for each major component of a biogas facility. It serves as a checklist-style reference for operators and technicians during facility inspection or routine maintenance.

Table 13. Key Commissioning Inspection Items for Biogas Facilities

Major Equipment	Key Inspection Items
Receiving & Supply Equipment	<ul style="list-style-type: none"> - Check scale and reception record accuracy, normal operation of supply pump - Functional test of automatic opening/closing facility - Odor and gas leakage check
Pretreatment Equipment	<ul style="list-style-type: none"> - Check for foreign object clogging or leaks - Check conveying equipment operation and flow direction - Power supply and overload protection system
Anaerobic Digester	<ul style="list-style-type: none"> - pH, temperature, gas production volume - Mixing efficiency and gas removal device performance - Internal pressure and safety device check

Biogas Utilization Equipment	<ul style="list-style-type: none"> - Check gas compression and drying system - Gas quality check (methane content, water content, etc.)
Digested Sludge Treatment Equipment	<ul style="list-style-type: none"> - Check sludge dewatering and transport system - Confirm performance and condition of treated sludge storage
Odor Control Equipment	<ul style="list-style-type: none"> - Check deodorization process efficiency - Operation of fans and scrubbers
Wastewater Treatment Equipment	<ul style="list-style-type: none"> - Check flow, pH, and pump operation - Confirm condition of final treated water (discharge location)